CLIMATE SYSTEM

Perspectives past and present

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UNDERSTANDING the intricate web of processes controlling interactions between the Earth's climate and its ecosystems is a daunting task, but an essential one if we are to play any kind of informed role in minimizing climate and ecosystem perturbations due to anthropogenic activities. Intergovernmental policy decisions on practices that carry a perceived threat to climate or ecosystem stability have been — as is clear from the present prevarication on CO_2 emission policy — largely based on balancing a desire for minimal perturbation against short-term economic costs; we simply do not yet have a sufficient physical, biological and chemical understanding of the integrated 'Earth system' to argue otherwise.

A conference in September*, convened by the International Geosphere–Biosphere Programme (IGBP), aimed to serve as a focus for steering future research towards the development of dynamic biogeochemical ecosystem models that interact realistically with the physical ocean–climate–land system. What emerged was a melting-pot of different models, rapidly evolving as a result of being continually constrained by data, yet liberated by ever more ingenious computational techniques. At this rate, the ability to predict the broad characteristics of regional climate — and the anthropogenic contribution to it — on seasonal to interannual timescales could be realised within the next ten years.

Our entire understanding of the functioning of the Earth system is based on observations. Characteristics of the Earth's past climate have been preserved in the geological, ice and vegetation records, noted by historians and, over the past few decades, measured directly. The varying timescales and resolutions of these observations dictate the timescales on which the Earth system can be modelled. The conference was tailored accordingly, being divided into sessions on the palaeo, historical, recent and future eras.

Changes over the past 200,000 years, encompassing the last ice-age and the preceding interglacial period, can give us a perspective on the functioning of the Earth system under natural forcing, such as changes in the Earth's orbit and ocean circulation. Studies over the past 2,000 years enable the growing influence of mankind to be followed, first as land-use changes (agriculture, deforestation, irrigation), then as industrialization (largely affecting trace gas emissions) over the past 150 years. On a yet shorter timescale, the past few decades have provided the most observations as well as being a period of relatively rapid change in atmospheric composition and land use.

Participants at the meeting were treated to a fascinating range of perspectives on our present 'best-guess' as to how the Earth system has changed and responded to change over each of these timescales. On the key question of what is happening now, and what will happen in the near future, the evidence is mounting that the elusive 'missing sink' of carbon (the fraction of anthropogenic CO_2 emissions that cannot be accounted for by present estimates of atmospheric, oceanic and terrestrial sinks) lies predominantly in the terrestrial biosphere. The ability to measure gas concentrations and their isotopic signatures with unprecedented accuracy now allows the detection of variations in the O_2/N_2 atmospheric ratio (R. Keeling, Scripps Inst. Oceanography) and the isotopic composition (for carbon and oxygen) of atmospheric CO_2 (P. Ciais, Commissariat à l'Energie Atomique). Measurements at various locations are already under way, and their continuation should allow the various CO_2 sinks to be located and quantified ever more accurately as the time-series data accrue.

Achieving this goal is crucial, as, if we cannot describe the present-day global carbon cycle, there is little hope of predicting what the future holds. And even if we can balance the global carbon budget, we must also understand the underlying processes. How robust is the terrestrial sink for anthropogenic CO_2? Will it saturate, and if so when, and how will it be affected by global change, such as changes in vegetation or nutrient cycling? Indeed, there were intriguing allusions (S. Piper, Scripps) to preliminary data analyses that suggest that the large terrestrial sink of anthropogenic carbon in the Northern Hemisphere may have been much less significant 10 years ago. If so, we may already be seeing a dynamic and evolving ecosystem response to global anthropogenic perturbation.

In general terms, we have a better understanding of the functioning of the atmosphere than of the ocean, and of the ocean than of the terrestrial biosphere. This ranking is reflected by the sophistication of existing models. The terrestrial biogeochemists are trailing because of a comparatively late start and what is probably a more complex system to model. But the first dynamic biogeochemical ecosystem models, aiming to simulate the full range of ecosystem responses to changing climate — such as vegetation changes or migration, and perturbations to the global biogeochemical and hydrological cycles — are just starting to emerge (F. Woodward, Univ. Sheffield; J. Melillo, Woods Hole Oceanographic Inst.; A. Friend, Inst. Terrestrial Ecology).

So where do we go from here? The half-dozen or so model intercomparison exercises presented revealed that, in general, global analyses are in better agreement than regional analyses, but that the discrepancies are large. The different models need to be better constrained by data in order to produce more accurate outputs. But global data sets are expensive, and resources are few, so we must invest wisely.

What are the right kind of data? One example of how to go about answering this question was given by I. Fung (Univ. Victoria). We are most likely to find direct field evidence for (and thus be able to quantify) the 'missing sink' in the ecosystems where the sink is both detectable and statistically significant compared to that due to natural variability. She applied a simple carbon model of the biosphere forced by 100-year data sets of temperature, precipitation, nitrogen deposition and atmospheric CO_2 concentrations to show how one might, in principle, optimize site selection and sampling strategy. Her analysis suggested that we are most likely to be able to make unequivocal observations of the 'missing' terrestrial carbon sink if we look in the soil carbon, over timescales of up to ten years or so, and where — geographically — to look (suitable sites seem to be few in North America and western Europe). This particular sampling strategy should not be taken too seriously, as the model lacks sophistication, but the principles of the approach were met with enthusiastic approval.

In the short term, there is the goodwill to share available data archives, to undertake more rigorous model intercomparisons as part of the process of model evolution, and to anticipate collective data needs. Can we achieve the goal of reliably predicting the broad characteristics of regional climate on seasonal to interannual timescales within the next ten years? G. Asrar (NASA) firmly believes so, and that the required remote-sensing framework is already in place. Predictions on decade timescales would be a few years further down the line, and those scientists working on what is possibly the critical piece in the jigsaw — modelling a dynamic interactive terrestrial biosphere — are not alarmed by this timetable. It seems that the expertise is in place and willing, as is the guiding framework of the IGBP. The key to success will probably be making the right measurements at the right places at the right times — and, as always in science, having the resources to do so. □

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